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AN ANALYSIS OF SEA TURTLE TAKE RATES IN THE HIGH-SEAS LONGLINE FISHERY IN THE EASTERN PACIFIC OCEAN

James V. Carretta
Southwest Fisheries Science Center
National Marine Fisheries Service
8604 La Jolla Shores Drive, La Jolla, CA 92037
jim.carretta@noaa.gov

SUMMARY

Sea turtle take rates (turtles per 1000 hooks fished and turtles per set) in the high-seas longline fishery are examined and compared for the two regions west and east of W150 longitude. In addition, take rates are summarized by longitude and calendar quarter for the area east of W150, which is the region most utilized by vessels landing in California. Data from both the 'Hawaii' and 'California' components of the longline fishery are used in these analyses, although fishing locations overlap between the two fisheries. At both *per set* and *per 1000 hooks* levels, loggerhead and leatherback sea turtle take rates are higher east of W150. Take rates of olive ridley turtles are higher west of W150.

Observed loggerhead take rates west and east of W150 are 0.085 and 0.112 per 1000 hooks, respectively. On a per set basis, the fraction of sets with loggerhead entanglements is 6.8% west of W150 and 8.5% east of W150. Loggerhead take rates are not significantly different between the two regions ($p = 0.202$, Fisher exact test).

Observed leatherback take rates west and east of W150 are 0.021 and 0.033 per 1000 hooks, respectively. On a per set basis, the percentage of sets with leatherback entanglements is 1.7% west of W150 and 2.5% east of W150. Leatherback take rates are not significantly different between the two regions ($p = 0.226$, Fisher exact test).

Observed olive ridley take rates west and east of W150 are 0.025 and 0.004 per 1000 hooks, respectively. On a per set basis, the percentage of sets with olive ridley entanglements is 2.0% west of W150 and 0.3% east of W150. Olive ridley take rates are significantly different between the two regions ($p = 0.003$, Fisher exact test).

East of W150, over half of all observed sets (53%) are in the 4th calendar quarter and most remaining sets (36%) are in the 1st quarter. No leatherback interactions are observed in the 1st quarter sets (0 interactions/210 sets). 4.5% of all 4th quarter sets show leatherback interactions (14 interactions/310 sets). The fraction of sets with leatherback turtle interactions in the 1st and 4th quarters is significantly different ($p = 0.0002$, Fisher exact Test). Loggerhead interactions occur in 17% of all 1st quarter sets (36 interactions/210 sets) and 3.5% of all 4th quarter sets (11 interactions/310 sets). The fraction of sets with loggerhead turtle interactions in the 1st and 4th quarters is significantly different ($p=0.00$, Fisher exact test).

Dataset

A tabular summary of the data analyzed is shown in Table 1. Data summaries for the area west of W150 longitude are provided by Bill Walsh of the NMFS Honolulu Office. Set and protected species data for the area east of W150 longitude are provided by Lyle Enriquez of the NMFS Long Beach Office for vessels operating out of California and by the NMFS Honolulu Laboratory for Hawaii-based vessels. Data for the area west of W150 spans 1994 through mid-2002 and data for the area east of W150 spans 1997 through February 2003. Data are for swordfish-style sets only.

	<i>Bill Walsh (Honolulu)</i>	<i>Lyle Enriquez (Long Beach)</i> <i>plus Honolulu Data</i>
	West of W150	East of W150
Leatherback Entanglements	32	15
Loggerhead Entanglements	129	50
Olive Ridley Entanglements	38	2
Green Turtle Entanglements	13	0
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Hooks Observed	1,513,596	444,833
Sets Observed	1,875	586
Mean Hooks per Set	807	759
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Leatherbacks per 1000 hooks	0.021	0.034
Loggerheads per 1000 hooks	0.085	0.112
Olive Ridleys per 1000 hooks	0.025	0.004
Greens per 1000 hooks	0.009	0.000
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Sets with Leatherbacks	32	15
Sets without Leatherbacks	1843	571
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Sets with Loggerheads	129	50
Sets without Loggerheads	1746	536
<hr/>		
Sets with Olive Ridleys	38	2
Sets without Olive Ridleys	1837	584
<hr/>		
Sets with Green Turtles	13	0
Sets without Green Turtles	1862	587

Comparison of Take Rates

Take rates of leatherback, loggerhead, and olive ridley sea turtles are examined using Fisher exact Tests with 2x2 contingency tables. I did not analyze green turtle take rates because no green turtles were observed taken east of W150 in this dataset. Two-tailed tests are performed to examine the null hypothesis that the proportion of sets with turtle interactions is equal between regions or seasons.

Leatherback Fisher Exact Test

The Fisher exact test is useful for comparing proportions in a 2x2 contingency table. Such a table is easily constructed in the case of comparing proportions of longline sets with and without turtle interactions between two areas or seasons. An example of a contingency table using the actual set data for leatherback turtles is given below.

	East	West	All sets
Sets with Turtles	15	32	47
Sets without Turtles	571	1843	2414
All sets	586	1875	2461

This table summarizes set-level data for the areas east and west of W150 for swordfish style sets only. The null hypothesis (two-tailed) being tested is whether the proportion of sets with leatherback interactions east and west of W150 are equal. In this table, 2.5% of *East* sets and 1.7% of *West* sets had leatherback interactions. The probability of observing this particular table given that the null hypothesis is true is 0.056. In order to calculate the two-tailed probability, the individual probabilities of observing more extreme cases of this table (in both directions) must be calculated. For example, the next most extreme table (in the direction of a higher proportion of East sets with turtles) is:

	East	West	All sets
Sets with Turtles	16	31	47
Sets without Turtles	570	1844	2414
All sets	586	1875	2461

The probability of observing this table if the null hypothesis were true is 0.035, which is less than the probability of observing the previous table. This makes sense, since the current table is more extreme in the direction of a higher proportion of East sets with turtles. One iteratively constructs tables for all possible combinations of this dataset and calculates the probability of each table being observed given the null hypothesis of equal proportions between regions. The probability of each table is calculated as:

$$P = \frac{R_1!R_2!C_1!C_2!}{n! \cdot f_{11}!f_{12}!f_{21}!f_{22}!}$$

where in the above table;

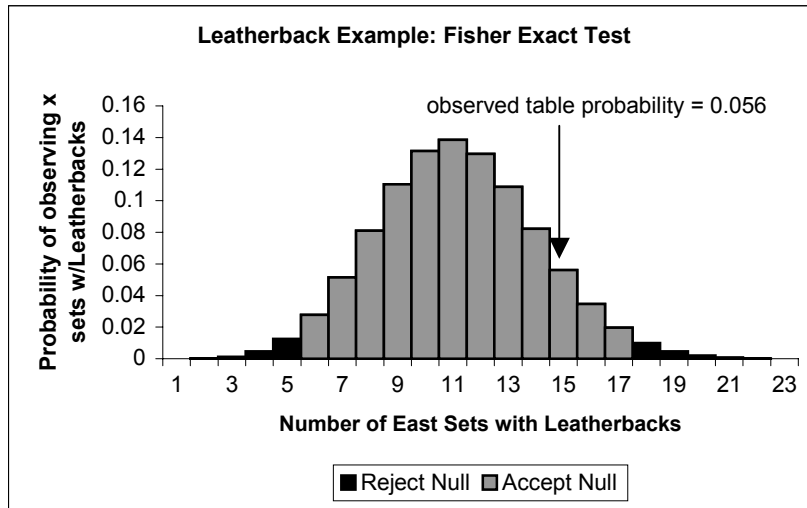
- R_1 = the sum of row 1 (**47**),
- R_2 = the sum of row 2 (**2414**),
- C_1 = the sum of column 1 (**586**),
- C_2 = the sum of column 2 (**1875**),

n = the sum of all samples (**2461**),
 f_{11} = the frequency in row 1, column 1 (**16**),
 f_{12} = the frequency in row 1, column 2 (**31**),
 f_{21} = the frequency in row 2, column 1 (**570**) and
 f_{22} = the frequency in row 2, column 2 (**1844**).

Because the values in this dataset involve the calculation of large values, I use Stirling's approximation to calculate factorials, where

$$\log X! = (X + 0.5) \log X - 0.434294 X + 0.39909.$$

The sum of all possible table probabilities is 1. The distribution of probabilities for each possible table is shown below.



The x-axis of this graph is truncated because the probability of observing greater than 23 East sets with leatherbacks is zero and values as extreme or greater than this do not contribute to the overall probability distribution. The two-tailed probability of observing a table at least this extreme is the sum of probabilities at least as extreme as that observed. In this case, the sum of probabilities of observing 1 to 7 East sets with leatherbacks is $0 + 0.0003 + 0.0013 + 0.0046 + 0.012 + 0.0278 + 0.0515$ respectively, plus the sum of probabilities of observing 15 or greater sets with leatherbacks ($0.056 + 0.0347 + 0.0196 + 0.01 + 0.0047 + 0.002 + 0.0008 + 0.0003 + 0.0001$). The sum of these probabilities is 0.226. Since this probability is greater than 0.05, we do not reject the null hypothesis. However, as the observed table probability is toward the right tail of the distribution, there is good evidence that the proportion of East sets with turtles is still 'higher' than West sets, even if there is not statistical significance at $\alpha = 0.05$. The resulting contingency table for the two-tailed leatherback Fisher exact test appears on the next page.

Leatherback 2x2 Contingency Table			
	East	West	All sets
Sets with Turtles	15	32	47
Sets without Turtles	571	1843	2414
All sets	586	1875	2461

2-tailed Fisher Exact Test
 Null: East equals West
Accept Null Hypothesis; p= 0.226

Table 2. Tabular summary of individual Fisher exact test probabilities for leatherback turtle example. The observed probability from the original 2x2 contingency table is highlighted.

Leatherback Turtles				
Number of Sets				
	East	West	East	West
<i>Probability</i>	<i>Turtles</i>	<i>Turtles</i>	<i>No Turtles</i>	<i>No Turtles</i>
0	1	46	585	1829
0.0003	2	45	584	1830
0.0013	3	44	583	1831
0.0046	4	43	582	1832
0.0126	5	42	581	1833
0.0278	6	41	580	1834
0.0515	7	40	579	1835
0.081	8	39	578	1836
0.1103	9	38	577	1837
0.1315	10	37	576	1838
0.1385	11	36	575	1839
0.1297	12	35	574	1840
0.1088	13	34	573	1841
0.0822	14	33	572	1842
0.0561	15	32	571	1843
0.0347	16	31	570	1844
0.0196	17	30	569	1845
0.01	18	29	568	1846
0.0047	19	28	567	1847
0.002	20	27	566	1848
0.0008	21	26	565	1849
0.0003	22	25	564	1850
0.0001	23	24	563	1851
0	24	23	562	1852

Loggerhead Fisher Exact Test

Results from the Fisher exact test and contingency table for loggerheads appears below. The null hypothesis that the proportion of sets East and West of W150 with loggerhead interactions is equal is **accepted** with a p -value of 0.202 .

Loggerhead 2x2 Contingency Table			
	East	West	All sets
Sets with Turtles	50	129	179
Sets without Turtles	536	1746	2282
All sets	586	1875	2461

2-tailed Fisher Exact Test
 Null: East equals West
Accept Null Hypothesis; $p=$ 0.202

The observed distribution of individual table probabilities appears below and in Table 3.

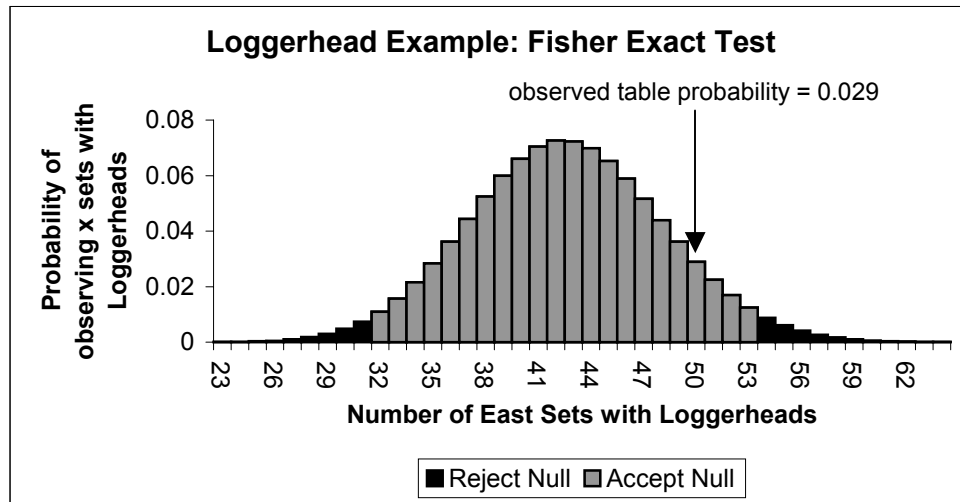


Table 3. Tabular summary of individual Fisher exact test probabilities for loggerhead turtle analysis. The observed probability from the original 2x2 contingency table is highlighted.

Loggerhead Turtles				
Number of Sets				
	East	West	East	West
Probability	Turtles	Turtles	No Turtles	No Turtles
0	22	157	564	1718
0.0001	23	156	563	1719
0.0001	24	155	562	1720
0.0003	25	154	561	1721
0.0005	26	153	560	1722
0.001	27	152	559	1723
0.0018	28	151	558	1724
0.003	29	150	557	1725
0.0048	30	149	556	1726
0.0074	31	148	555	1727
0.011	32	147	554	1728
0.0157	33	146	553	1729
0.0215	34	145	552	1730
0.0284	35	144	551	1731
0.0362	36	143	550	1732
0.0444	37	142	549	1733
0.0525	38	141	548	1734
0.0599	39	140	547	1735
0.0661	40	139	546	1736
0.0704	41	138	545	1737
0.0726	42	137	544	1738
0.0723	43	136	543	1739
0.0698	44	135	542	1740
0.0652	45	134	541	1741
0.0589	46	133	540	1742
0.0517	47	132	539	1743
0.0439	48	131	538	1744
0.0362	49	130	537	1745
0.0289	50	129	536	1746
0.0225	51	128	535	1747
0.0169	52	127	534	1748
0.0124	53	126	533	1749
0.0088	54	125	532	1750
0.0061	55	124	531	1751
0.0041	56	123	530	1752
0.0027	57	122	529	1753
0.0017	58	121	528	1754
0.001	59	120	527	1755
0.0006	60	119	526	1756
0.0004	61	118	525	1757
0.0002	62	117	524	1758
0.0001	63	116	523	1759
0.0001	64	115	522	1760
0	65	114	521	1761

Olive Ridley Fisher exact test

Results from the Fisher exact test and contingency table for olive ridleys appears below. The null hypothesis that the proportion of sets East and West of W150 with olive ridley interactions is equal is **rejected** with a p -value of 0.003 .

	West	East	All sets
Sets with Turtles	38	2	40
Sets without Turtles	1837	584	2421
All sets	1875	586	2461

2-tailed Fisher Exact Test
 Null: East equals West
Reject Null Hypothesis; $p=$ 0.003

The distribution of individual table probabilities for the olive ridley analysis is shown below and in Table 4.

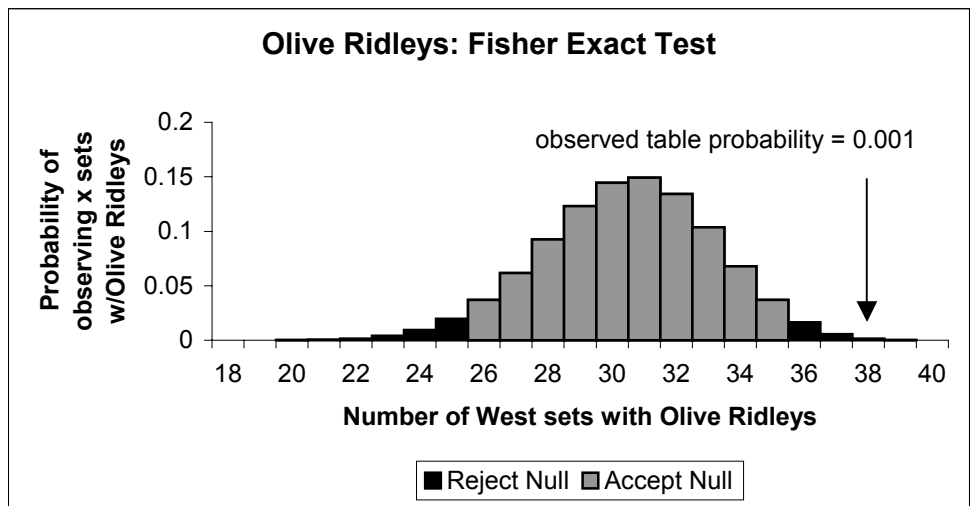


Table 4. Tabular summary of individual Fisher exact test probabilities for olive ridley turtle analysis. The observed probability from the original 2x2 contingency table is highlighted.

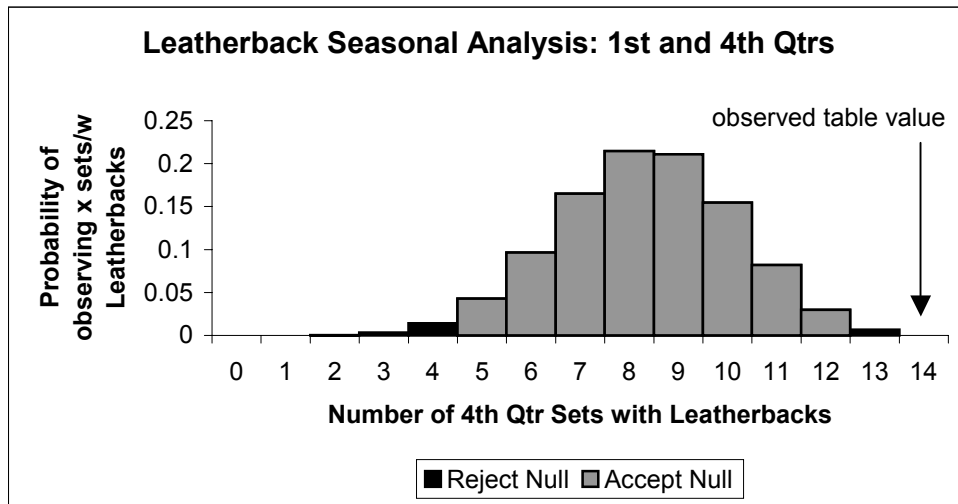
Olive Ridley Turtles				
Number of Sets				
	West	East	West	East
Probability	Turtles	Turtles	No Turtles	No Turtles
0	18	22	1857	564
0.0001	19	21	1856	565
0.0002	20	20	1855	566
0.0006	21	19	1854	567
0.0016	22	18	1853	568
0.0041	23	17	1852	569
0.0095	24	16	1851	570
0.0198	25	15	1850	571
0.037	26	14	1849	572
0.0618	27	13	1848	573
0.0925	28	12	1847	574
0.123	29	11	1846	575
0.1446	30	10	1845	576
0.1493	31	9	1844	577
0.1341	32	8	1843	578
0.1036	33	7	1842	579
0.0679	34	6	1841	580
0.037	35	5	1840	581
0.0163	36	4	1839	582
0.0056	37	3	1838	583
0.0014	38	2	1837	584
0.0002	39	1	1836	585
0	40	0	1835	586

Seasonal Analysis Summary of Leatherback Take Rates east of W150

The proportion of sets with leatherback takes east of W150 is significantly different in the 1st and 4th calendar quarters. No leatherback interactions are observed from 210 1st quarter sets and 4.5% (14 of 310) of 4th quarter sets have leatherback interactions. There are insufficient data in the remaining two calendar quarters for comparison. Results of a Fisher exact test for this analysis is shown below.

Leatherback 2x2 Contingency Table			
Area East of W150 only			
	4th Qtr	1st Qtr	All sets
Sets with Turtles	14	0	14
Sets without Turtles	296	210	506
All sets	310	210	520

2-tailed Fisher Exact Test
 Null: East equals West
Reject Null Hypothesis; p= 0.0002

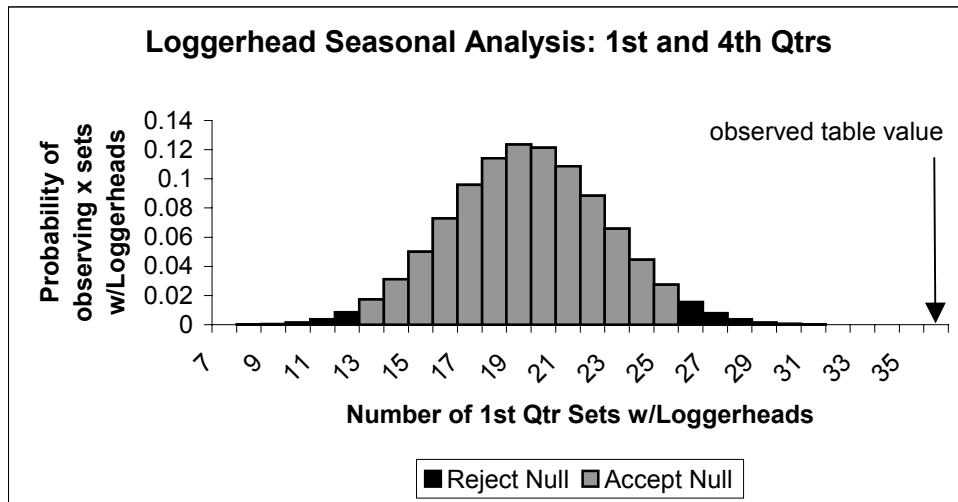


Seasonal Analysis Summary of Loggerhead Take Rates east of W150

The proportion of sets with loggerhead takes east of W150 is significantly different in the 1st and 4th calendar quarters. Loggerhead interactions occur in 17% (36 of 210) of all 1st quarter sets and 3.5% (11 of 310) of all 4th quarter sets. There are insufficient data in the remaining two calendar quarters for comparison. Results of a Fisher exact test for this analysis is shown below.

Loggerhead 2x2 Contingency Table			
	Area East of W150 only		
	1st Qtr	4th Qtr	All sets
Sets with Turtles	36	11	47
Sets without Turtles	174	299	473
All sets	210	310	520

2-tailed Fisher Exact Test
 Null: East equals West
Reject Null Hypothesis; p= 0.0000



Appendix: Summary of quarterly take rates (turtles per 1000 hooks) for the area east of W150.

1st Quarter Hawaii (1997-2001) and CA (2001-2003)

ALL SETS	W of 130	E of 130	per 1000 hooks	
			West	East
Sets obs	210	0		
Hooks obs	153572	0		
Loggerheads	36	0	.23442	.00000
Leatherbacks	0	0	.00000	.00000
Olive Ridley	0	0	.00000	.00000
BF Albatross	45	0	.29302	.00000
LA Albatross	36	0	.23442	.00000

Turtles per 1000 hooks
W of 130 .234418
E of 130 .000000
East+West .234418

ALL SETS	W of 135	E of 135	per 1000 hooks	
			West	East
Sets obs	210	0		
Hooks obs	153572	0		
Loggerheads	36	0	.23442	.00000
Leatherbacks	0	0	.00000	.00000
Olive Ridley	0	0	.00000	.00000
BF Albatross	45	0	.29302	.00000
LA Albatross	36	0	.23442	.00000

Turtles per 1000 hooks
W of 135 .234418
E of 135 .000000
East+West .234418

ALL SETS	W of 140	E of 140	per 1000 hooks	
			West	East
Sets obs	193	17		
Hooks obs	140339	13233		
Loggerheads	34	2	.24227	.15114
Leatherbacks	0	0	.00000	.00000
Olive Ridley	0	0	.00000	.00000
BF Albatross	40	5	.28502	.37784
LA Albatross	36	0	.25652	.00000

Turtles per 1000 hooks
W of 140 .242271
E of 140 .151137
East+West .234418

ALL SETS	W of 145	E of 145	per 1000 hooks	
			West	East
Sets obs	127	83		
Hooks obs	92540	61032		
Loggerheads	21	15	.22693	.24577
Leatherbacks	0	0	.00000	.00000
Olive Ridley	0	0	.00000	.00000
BF Albatross	26	19	.28096	.31131
LA Albatross	25	11	.27015	.18023

Turtles per 1000 hooks
W of 145 .226929
E of 145 .245773
East+West .234418

2nd Quarter Hawaii (1997-2001) and CA (2001-2003) sets

ALL SETS	W of 130	E of 130	per 1000 hooks	
			West	East
Sets obs	22	0		
Hooks obs	24728	0		
Loggerheads	6	0	.24264	.00000
Leatherbacks	1	0	.04044	.00000
Olive Ridley	1	0	.04044	.00000
BF Albatross	13	0	.52572	.00000
LA Albatross	0	0	.00000	.00000

Turtles per 1000 hooks
W of 130 .323520
E of 130 .000000
East+West .323520

ALL SETS	W of 135	E of 135	per 1000 hooks	
			West	East
Sets obs	21	1		
Hooks obs	23658	1070		
Loggerheads	6	0	.25361	.00000
Leatherbacks	1	0	.04227	.00000
Olive Ridley	1	0	.04227	.00000
BF Albatross	13	0	.54950	.00000
LA Albatross	0	0	.00000	.00000

Turtles per 1000 hooks
W of 135 .338152
E of 135 .000000
East+West .323520

ALL SETS	W of 140	E of 140	per 1000 hooks	
			West	East
Sets obs	19	3		
Hooks obs	21590	3138		
Loggerheads	6	0	.27791	.00000
Leatherbacks	1	0	.04632	.00000
Olive Ridley	1	0	.04632	.00000
BF Albatross	10	3	.46318	.95602
LA Albatross	0	0	.00000	.00000

Turtles per 1000 hooks
W of 140 .370542
E of 140 .000000
East+West .323520

ALL SETS	W of 145	E of 145	per 1000 hooks	
			West	East
Sets obs	5	17		
Hooks obs	4335	20393		
Loggerheads	0	6	.00000	.29422
Leatherbacks	1	0	.23068	.00000
Olive Ridley	0	1	.00000	.04904
BF Albatross	0	13	.00000	.63747
LA Albatross	0	0	.00000	.00000

Turtles per 1000 hooks
W of 145 .230681
E of 145 .343255
East+West .323520

3rd Quarter Hawaii (1997-2001) and CA (2001-2003) sets

ALL SETS	W of 130	E of 130	per 1000 hooks	
			West	East
Sets obs	18	26		
Hooks obs	13541	19207		
Loggerheads	3	0	.22155	.00000
Leatherbacks	0	0	.00000	.00000
Olive Ridley	0	0	.00000	.00000
BF Albatross	4	2	.29540	.10413
LA Albatross	0	0	.00000	.00000

Turtles per 1000 hooks
W of 130 .221549
E of 130 .000000
East+West .091609

ALL SETS	W of 135	E of 135	per 1000 hooks	
			West	East
Sets obs	0	44		
Hooks obs	0	32748		
Loggerheads	0	3	.00000	.09161
Leatherbacks	0	0	.00000	.00000
Olive Ridley	0	0	.00000	.00000
BF Albatross	0	6	.00000	.18322
LA Albatross	0	0	.00000	.00000

Turtles per 1000 hooks
W of 135 .000000
E of 135 .091609
East+West .091609

ALL SETS	W of 140	E of 140	per 1000 hooks	
			West	East
Sets obs	0	44		
Hooks obs	0	32748		
Loggerheads	0	3	.00000	.09161
Leatherbacks	0	0	.00000	.00000
Olive Ridley	0	0	.00000	.00000
BF Albatross	0	6	.00000	.18322
LA Albatross	0	0	.00000	.00000

Turtles per 1000 hooks
W of 140 .000000
E of 140 .091609
East+West .091609

ALL SETS	W of 145	E of 145	per 1000 hooks	
			West	East
Sets obs	0	44		
Hooks obs	0	32748		
Loggerheads	0	3	.00000	.09161
Leatherbacks	0	0	.00000	.00000
Olive Ridley	0	0	.00000	.00000
BF Albatross	0	6	.00000	.18322
LA Albatross	0	0	.00000	.00000

Turtles per 1000 hooks
W of 145 .000000
E of 145 .091609
East+West .091609

4th Quarter Hawaii (1997-2001) and CA (2001-2003) sets

ALL SETS	W of 130	E of 130	per 1000 hooks	
			West	East
Sets obs	242	68		
Hooks obs	182886	50899		
Loggerheads	11	0	.06015	.00000
Leatherbacks	11	3	.06015	.05894
Olive Ridley	1	0	.00547	.00000
BF Albatross	25	13	.13670	.25541
LA Albatross	3	0	.01640	.00000

Turtles per 1000 hooks
W of 130 .125761
E of 130 .058940
East+West .111213

ALL SETS	W of 135	E of 135	per 1000 hooks	
			West	East
Sets obs	196	114		
Hooks obs	148167	85618		
Loggerheads	11	0	.07424	.00000
Leatherbacks	10	4	.06749	.04672
Olive Ridley	1	0	.00675	.00000
BF Albatross	18	20	.12148	.23360
LA Albatross	3	0	.02025	.00000

Turtles per 1000 hooks
W of 135 .148481
E of 135 .046719
East+West .111213

ALL SETS	W of 140	E of 140	per 1000 hooks	
			West	East
Sets obs	142	168		
Hooks obs	102477	131308		
Loggerheads	8	3	.07807	.02285
Leatherbacks	8	6	.07807	.04569
Olive Ridley	1	0	.00976	.00000
BF Albatross	11	27	.10734	.20562
LA Albatross	3	0	.02927	.00000

Turtles per 1000 hooks
W of 140 .165891
E of 140 .068541
East+West .111213

ALL SETS	W of 145	E of 145	per 1000 hooks	
			West	East
Sets obs	38	272		
Hooks obs	32293	201492		
Loggerheads	5	6	.15483	.02978
Leatherbacks	2	12	.06193	.05956
Olive Ridley	0	1	.00000	.00496
BF Albatross	1	37	.03097	.18363
LA Albatross	1	2	.03097	.00993

Turtles per 1000 hooks
W of 145 .216765
E of 145 .094297
East+West .111213